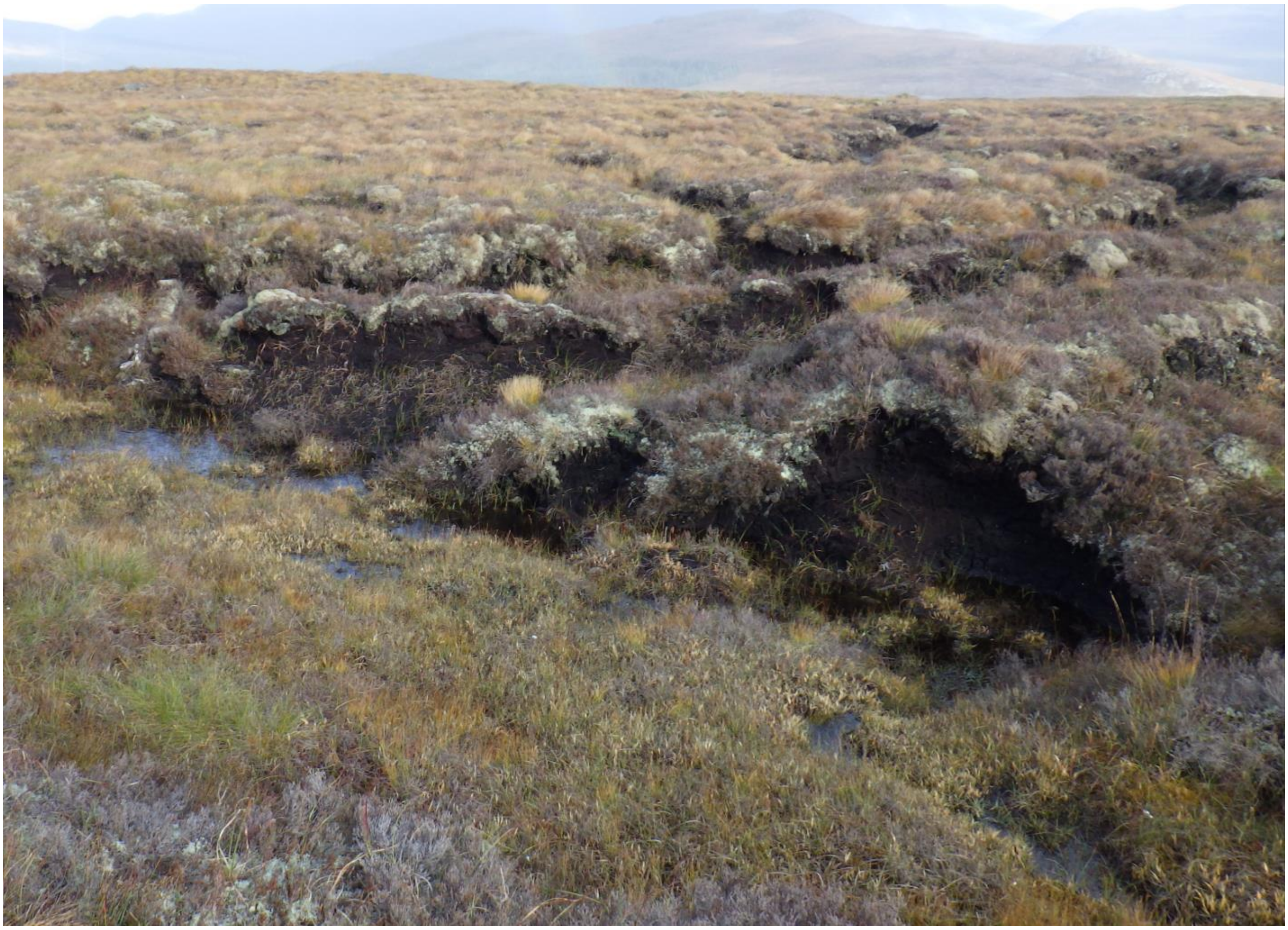

Kirkan Wind Farm Limited

Kirkan Wind Farm: Peat Slide Risk Assessment

Technical Appendix 9.1

650395-P9.1 (02)

MARCH 2019

RSK GENERAL NOTES

Project No.: 650395-P9.1 (02)

Title: Kirkan Wind Farm: Peat Slide Risk Assessment, Technical Appendix 9.1

Client: Kirkan Wind Farm Limited

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1 INTRODUCTION

1.1 This report provides a Peat Slide Risk Assessment (PSRA) for Kirkan Wind Farm and associated development infrastructure.

1.2 The report forms a Technical Appendix to the Environmental Impact Assessment Report (EIAR) for Kirkan Wind Farm and should be read in conjunction with this document. It has been produced in response to concerns over development in areas of peatland relating specifically to the risk of induced instability within peat caused by proposed development.

1.3 This report describes the existing peatland conditions at the project area and identifies and assesses the potential impacts that may be caused by the proposed development. This includes potential risks from induced peat instability. Design and mitigation methods to avoid or minimise these risks are set out, along with a number of good construction practices that would be employed during all project works.

Location

1.4 The project area is located on Strathvaich Estate, in the Garve District of the Ross and Cromarty Region of the Highlands. The project area lies to the south of the A835 trunk road from Garve to Ullapool, and to the east of the operational Corriemoillie and Lochluichart wind farms.

1.5 The project area is approximately 5.3 km north-west of the village of Garve and approximately 19 km west-north-west of Dingwall. Ullapool is approximately 32 km to the north-west. The Aultguish Inn lies 490 m north-west of the project area's northern boundary.

Development proposals

1.6 The Kirkan Wind Farm proposal includes the following key elements:

- 17 turbines, of approximately up to 4.8 MW each and a maximum tip height of 175 m;
- Hardstanding areas at the base of each turbine, with a maximum total area of 1,850 m^2;
- Up to two permanent meteorological masts and associated hardstanding areas;
- 10,835 m of access track with associated watercourse crossings, of which 9,975 m is new access track, and 860 m is upgrade to existing track;
- An operations control building with parking and temporary welfare facilities;
- A substation compound;
- A substation construction compound, providing space for a prospective modular energy storage facility;
- Telecommunications equipment, including masts;
- Up to three temporary construction compounds;
- Two borrow pits, to provide suitable rock for access tracks, turbine bases and hard standings; and

- Underground cabling linking the turbines with the substation.

1.7 Full details of the project design are provided in Chapter 2 of the EIAR.

Aims

1.8 This report aims to undertake a review of available relevant project area information, including all peat depth and peat condition records, in order to provide an assessment of the risk of peat instability within the project area. Recommendations will be made for mitigation measures and specific construction methods that should be implemented in order to minimise the risk of inducing instability in the peat during construction works.

Assessment method

1.9 The assessment has involved the following stages:

- Desk study;
- Site reconnaissance;
- Peat condition assessment;
- Hazard and risk assessment;
- Detailed assessment;
- Mitigation.

2 DESK STUDY

Information sources

2.1 The desk study involved a review of available relevant information sources on the ground conditions at the Kirkan Wind Farm project area. Information sources included:

- Ordnance Survey mapping at 1:50,000, 1:25,000 and VectorMap Local raster mapping, Terrain 50 digital terrain model grid and contours, and OpenData mapping;
- Ordnance Survey MasterMap high-resolution orthorectified aerial imagery;
- British Geological Survey online geological mapping, 1:50,000 scale;
- Scotland's Soils digital soil mapping, 1:250,000 scale;
- Data provided by the landowner including peat depth data and reporting by Quadrat Scotland Ltd;
- Peat depth data collected by Avian Ecology and RSKW;
- Archive and extensive project area data held by RSK Group.

Historical information

2.2 There are no available records that indicate any historical peat slides in the area around Corriemoillie Forest, which includes the project area, or in other parts of the wider Strathvaich Estate. The Quadrat Scotland report into peatland condition on Strathvaich Estate did not identify any indications of peat instability within their survey effort (Quadrat Scotland, 2015).

2.3 A detailed inspection of available satellite and aerial photography revealed a number of small landslips along the eastern side of Beinn nan Cabag. This was confirmed by the site reconnaissance visit (Figure 9.1.1). This slope is very steep, with slope angles in excess of 20° for much of the eastern face.

Figure 9.1.1: Landslips on Beinn nan Cabag. View south-south-west from T04.

2.4 There is no notable peat development on the slope, with visible soils of approximately 0.2-0.3 m thickness. The failure surface appeared in all cases to be within the mineral soil below the organic soil cover. As the landslips are on ground outwith the Strathvaich Estate boundary, closer access to the slips was not possible.

Climate

2.5 Kirkan Wind Farm is located in the Scottish Highlands, within the UK Meteorological (Met) Office's Northern Scotland regional climatic area. Much of Northern Scotland is exposed to the rain-bearing westerly winds, particularly the Western Isles and areas along the west coast. The location of the proposed development, roughly in the centre of the region and to the east of areas of higher ground, affords it some protection from the prevailing westerly and south-westerly rainfall directions.

2.6 Average annual rainfall for the project area catchments varies between 1,315 mm and 1,425 mm (CEH, 2018), reflecting the elevation and slope aspect of the catchments. Average annual rainfall for the climate monitoring station at Loch Glascarnoch is 1,767 mm (Met Office, 2018).

2.7 The Northern Scotland climatic area includes the wettest part of the UK, north-west of Fort William, which experiences over 4,000 mm of rainfall per year. In contrast, the Moray Coast east of Inverness experiences around 700 mm of rainfall.

Topography

2.8 The project area is located over a broad slope with a north to north-easterly aspect. The highest ground is located along the south-western project area boundary at approximately 420 m above Ordnance Datum (AOD), with land continuing to rise beyond the boundary to the summit of Beinn nan Cabag at 474 m AOD. The lowest part of the project area is at the northern boundary, at approximately 220 m AOD.

2.9 Dominant project area slopes are gentle, although the topography is undulating and varied on a local scale. Notable exceptions are the eastern and western sides of Beinn nan Cabag, which have steep slopes. The steepest sections are located outwith the project area. Infrastructure is largely confined to areas with relatively gentle slopes for practical reasons, although the topography within the development area is undulating and varied on a local scale. Notably steep slopes have been avoided.

Geology

Bedrock geology

2.10 The bedrock in the Kirkan area is largely Pre-Cambrian in age. The western part belongs to the Crom Psammite Formation, part of the Moine Supergroup. This is described as a well-bedded, flaggy to massive, white to pale grey or buff psammite. The lower sections include garnet-bearing semipelite bands and the upper part is locally pebbly.

2.11 The eastern part of the project area is underlain by the Inchbae augen gneiss, a granitic gneiss forming part of the Carn Chuinneag Complex. This distinctive rock is described as a coarse biotite-granite gneiss with abundant feldspar augen ('eyes').

2.12 A small area around Beinn nan Cabag, in the south of the project area, is underlain by the Ousdale Arkose Formation, part of the Devonian-age Old Red Sandstone system. The rock is described as a red feldspar-rich conglomerate.

2.13 A major regional fault, the Strathconon Fault, runs through the project area from just west of Beinn nan Cabag to Black Bridge (BGS, 2018; Johnstone and Mykura, 1989). There are no records of recent or historical activity along the fault within the project area and immediate surroundings (BGS, 2019).

Superficial geology

2.14 Much of the project area is overlain by a blanket of glacial deposits, described as diamicton, gravel, sand and silt. Diamicton is a very variable glacial sediment consisting of unsorted material ranging in size from clay to boulders, usually with a matrix of clay to sand. It was formerly known as till or boulder clay.

2.15 The river valleys have deposits of alluvium, a mixture of clay, silt, sand and gravel. These are confined to the River Glascarnoch/Black Water channel and the lower reaches of the main project area watercourses and tend to be ribbon-like in form.

2.16 The south-western part of the project area is shown to have peat deposits. These extend from the upper reaches of Allt Giubhais Beag, skirting the western and southern slopes of Sìthean nan Cearc, to the upper reaches of Allt Bad an t-Seabhaig. Some outlying areas are indicated along the Allt Glac an t-Sìthein.

Soils and peat

2.17 The Soil Survey of Scotland digital soils mapping shows eight soil types within the proposed development area. Details are provided in Table 9.1.1

Table 9.1.1: Soil types within the project area

Soil Assoc.	Parent Material	Component Soils	Landforms	Vegetation	Area %
Countess-wells	Drifts derived from granites and granitic rocks	Peaty gleys, peat; some peaty podzols and peaty rankers	Hills and undulating lowlands with gentle and strong slopes; moderately rocky	Bog and northern bog heather moor; blanket and northern blanket bog; moist Atlantic heather moor	41.1%
		Peaty podzols, peat, peaty gleys	Hummocky valley and slope moraines, often bouldery	Moist Atlantic heather moor; blanket bog; bog heather moor	23.2%
		Peaty gleys, peat; some peaty podzols	Undulating uplands and hills with gentle and strong slopes; non- and slightly rocky	Bog and northern bog heather moor; blanket and northern blanket bog; moist Atlantic heather moor	9.4%
Hatton	Drifts derived from Middle & Lower Old Red Sandstone conglomerates	Peaty and humous-iron podzols; some rankers and peaty gleys	Hills and valley sides with strong and steep slopes; moderately rocky	Dry and moist Atlantic heather moor; acid bent-fescue grassland	9.3%

Soil Assoc.	Parent Material	Component Soils	Landforms	Vegetation	Area %
Organic	Organic deposits	Blanket peat	Uplands and northern lowlandswith gentle and strong slopes	Blanket and northern blanket bog; upland and flying bent bog; deer-grass bog; sedge mires	8.0%
Arkaig	Drifts derived from schists, gneisses, granulites and quartzites, principally of the Moine Series	Peat, peaty gleys, peaty podzols	Undulating lowlands and uplands, with gentle and strong slopes; non-rocky	Bog and northern bog heather moor; blanket and northern blanket bog; moist Atlantic heather moor	4.9%
		Peaty podzols, peat, peaty gleys	Hummocky valley and slope moraines, often bouldery	Bog and northern bog heather moor; blanket and northern blanket bog; moist Atlantic heather moor	3.4%
		Peaty gleys, peat; some peaty podzols and peaty rankers	Undulating hills with gentle and strong slopes; moderately rocky	Bog and northern bog heather moor; moist Atlantic heather moor; blanket and northern blanket bog	0.8%

2.18 The Soil Survey mapping does not identify extensive blanket peat within the project area, although almost all the project area soils are noted to include peat or peaty components, typically peaty podzols and peaty gleys.

2.19 The peat depth survey confirms that peat is present in the area and has fairly broad coverage. Much of the peat is shallow, although some areas of deeper peat are present. These areas are typically well-defined and usually form small basins between the hill crests and around the headwater areas of the watercourses.

2.20 Minor evidence of peat pipe development was identified, notably within the col area between the northern end of Beinn nan Cabag and Sìthean nan Cearc, a short distance beyond the project area boundary. Part of the pipe had collapsed, but there were no other indications of instability within the immediate area.

2.21 Some areas of peat showed development of minor peat hagging and formation of erosion channels. These are relatively localised, with the main area within the development area present around Turbine 4. Peat hag development mainly reflects the natural direction of surface water drainage across the hillslope.

Hydrogeology

2.22 The Moine psammites and granitic gneisses present in the area are generally classed as a very low productivity aquifer. The Old Red Sandstone strata in this area are classed as a low productivity aquifer. This means that natural groundwater flow within the project area bedrock is limited. Groundwater flow is concentrated principally within the near-surface weathered zone, which typically extends to around 1-2 m below ground surface.

Groundwater storage and flow at deeper levels requires the presence of a network of fractures within the bedrock, which are infrequent and often isolated in these strata.

2.23 Regional groundwater flow will tend to mimic the natural topography, flowing north and east towards the Glascarnoch River/Black Water in this area. It is likely that natural groundwater discharges will be partly via small flows to springs and streams on the hill slope and partly to the Glascarnoch River/Black Water system. The desk study and site visit confirmed the presence of a small number of minor springs or seepage points in the upper (south-western) part of the project area, around the outcrop of the Ousdale Arkose which forms Beinn nan Cabag. The springs are mainly located along or slightly below the boundary between the Ousdale Arkose and the underlying Inchbae augen gneiss, indicating that the augen gneiss is effectively impermeable in areas away from significant fracturing.

2.24 The overlying glacial deposits are also classed as a low productivity aquifer. The larger areas of alluvial and river terrace deposits along the Glascarnoch River/Black Water are indicated to be a high productivity aquifer; however, their areal extent means that their productivity would be restricted by the small area and thickness of the alluvial bodies.

2.25 The peat bodies will also hold some groundwater. Flow within peat is known to be extremely slow, although it can contribute some limited baseflow to local burns. The main areas of peat within the project area are located on saddle areas and will provide some input to watercourse headwaters, in particular helping to maintain flow during dry periods.

Hydrology

2.26 The project area lies entirely within the catchment of the Glascarnoch River/Black Water system with project area drainage principally directed to the north and north-east. The Glascarnoch River lies immediately north of the northern project area boundary.

2.27 From Inchbae, the Glascarnoch/Black Water catchment covers an area of 181 km^2. It includes two main waterbodies: Loch Glascarnoch located approximately 750 m west of the project area boundary, and Loch Vaich 4.5 km to the north. The Glascarnoch/Black Water forms a tributary to the River Conon. The catchment lies at an elevation between 165 m AOD at Inchbae to a maximum of 1,084 m AOD at the summit of Beinn Dearg, north-west of Loch Glascarnoch.

2.28 Three main watercourses provide drainage within the project area. All three drain north and north-east, forming tributaries to the Glascarnoch/Black Water system. A number of minor watercourses also drain into the Glascarnoch/Black Water system.

2.29 The Catchment Wetness Index, PROPWET, for the three project area catchments is 0.74, indicating the project area is wet for 74% of the time. The area has a relatively low Baseflow Index, indicating that groundwater contribution is of limited importance to project area watercourses. The Standard Percentage Runoff is relatively high, indicating that 50-55% of project area rainfall is converted into surface runoff from rainfall events. Catchment statistics are derived from the Flood Estimation Handbook Web Service (CEH, 2018).

Aerial photography

2.30 High-resolution orthorectified colour aerial photography for the project area has been made available for this assessment.

2.31 The project area is largely characterised by a mosaic of brown and green areas, with some patches of pale grey and stripy patches of a darker green.

2.32 The brown and green mosaic relates to natural topographical changes and surface drainage patterns, with the brown areas marking areas of sedge-rich vegetation and areas of peatland development. It is difficult to differentiate between the two habitat types based simply on the aerial photography, as the colours are similar.

2.33 The green areas are divided into a pale yellow or straw-green and a brighter green. The pale straw-green appears to identify areas of more grass-dominated vegetation within the heather, possibly indicating better drainage. The brighter green follows diffuse drainage paths down the slope and also identifies watercourse channels and broader boggy areas associated with the watercourses.

2.34 The pale grey patches identify bedrock exposure at surface. These are more dominant in the southern part of the development area and beyond the project area boundary to the south and east, with a few other isolated patches visible in other areas. Additional bedrock exposure is visible in the western part of the project area, as patches of a pale buff. These tend to blend with the brown vegetation and are only visible on close inspection.

2.35 The stripy darker green has a characteristic texture and marks the area of woodland planting, where the stripy effect identifies the planting in rows.

2.36 A network of narrow dark brown strips is apparent in the western part of the project area and beyond the boundary. These identify areas of peat hagging and associated drainage channels developing from the hags. A small area of bare peat is apparent between Turbines 4 and 7 but there are no extensive areas of unvegetated peat within the project area. More extensive peat hagging and development of bare peat is apparent south of the project area, to the east of the Beinn nan Cabag ridge.

Vegetation

2.37 National vegetation classification (NVC) survey mapping of the project area indicates that there are three dominant communities present:

- M6 – *Carex echinata – Sphagnum recurvum/auriculatum* mire;
- M15 – *Scirpus cespitosus – Erica tetralix* wet heath;
- M17 – *Scirpus cespitosus – Eriophorum vaginatum* blanket mire.

2.38 The project area is largely covered with a mosaic of NVC communities M15 and M17. Areas of M6 mire have been identified along the main watercourse valleys.

2.39 Part of the project area is under native woodland planting, largely a mix of native hardwood species and Scots pine.

2.40 The higher plateau areas, notably around the col between Sìthean nan Cearc and Beinn nan Cabag, and the broad relatively flat region immediately below and east of Beinn nan Cabag, show development of extensive peatland communities. These areas correspond with the mapped M17 habitat in this part of the project area.

3 SITE RECONNAISSANCE

3.1 A walkover survey of the project area was undertaken by RSKW, accompanied by members of the design team, on 2nd, 3rd and 4th August 2018. The scope of the survey included a reconnaissance survey of the project area and its immediate surroundings, plus mapping of the geomorphology and local-scale hydrology of the project area. The survey covered the entire project area, with a particular focus on the development area where infrastructure is planned and potential access routes into and across the project area. The weather during the survey was sunny with occasional light showers, some cloud cover notably on the higher hills and a light breeze. Visibility was excellent throughout.

3.2 The areas described below provide good coverage of the project area, detailing the range of landforms, vegetation and erosion patterns encountered. An indication of the proposed infrastructure is provided on the photographs; these are approximate, and reference should be made to the detailed design drawings for full details.

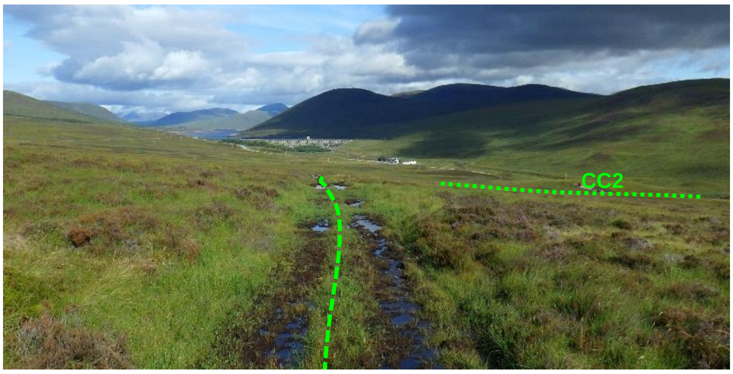
3.3 Reference is made to peat hagging, a form of erosion specific to peat. The peat develops channels which form breaks in the surface vegetation, exposing bare peat surfaces which are then more susceptible to erosion. Over time, this can lead to the development of a network of complex and sinuous channels through the peat and can lead to the formation of isolated peat 'islands'. In extreme situations, the peat body can be completely removed to leave bare mineral soil. Peat hagging is a natural process but can be exacerbated by poor land management practices including overgrazing and trampling from deer, sheep and cattle, extensive muirburn from grouse moor management, and uncontrolled off-road vehicle activity.

3.4 The development of peat hagging at Kirkan is relatively minor and there are no significant areas of exposed bare peat. Project infrastructure has been planned to avoid these areas as far as possible, to minimise the risk of increasing the natural erosion processes.

(A) View of project area entrance looking west from NGR NH 3584 7015.

View shows the access route into the project area from the A835, plus the two entrance area construction compounds CC1 and CC2.

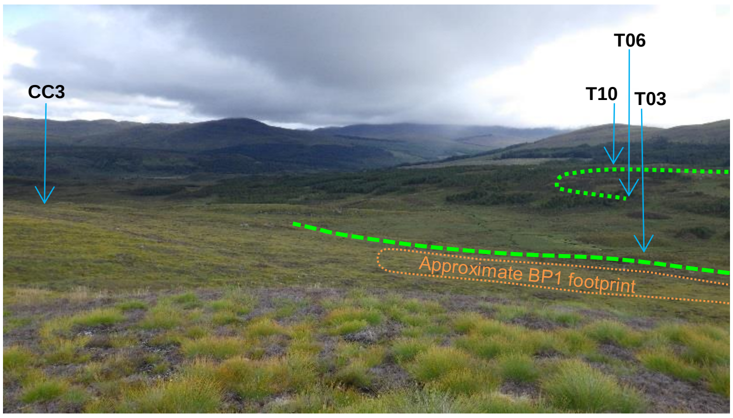
Peat is absent across this area, with areas of made ground forming a parking area.



(B) View along drover's track looking west from NGR NH 3593 6949.

View shows the access route into the project area, making use of the existing drover's track. CC2 marks the upper entrance construction compound.

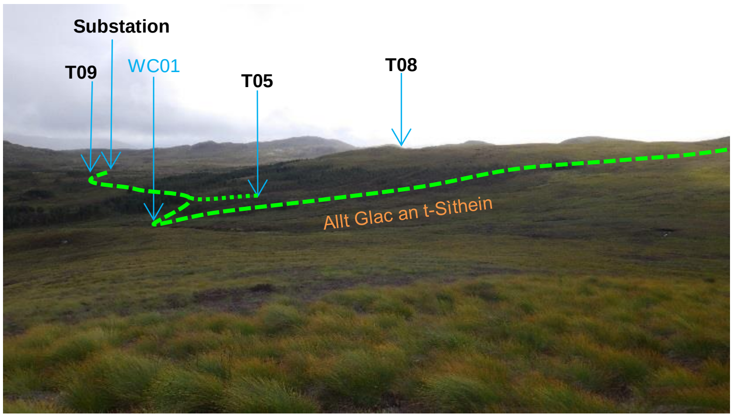
Peat is thin or absent across this area. Vegetation is mixed heather, grass and sedges.



(C) View across northern development area looking east from NGR NH 3605 6847.

View shows Turbine 3 and Borrow Pit 1 in the foreground, with Turbines 6 and 10 in the back-ground; CC3 is out of sight behind the left-hand slope.

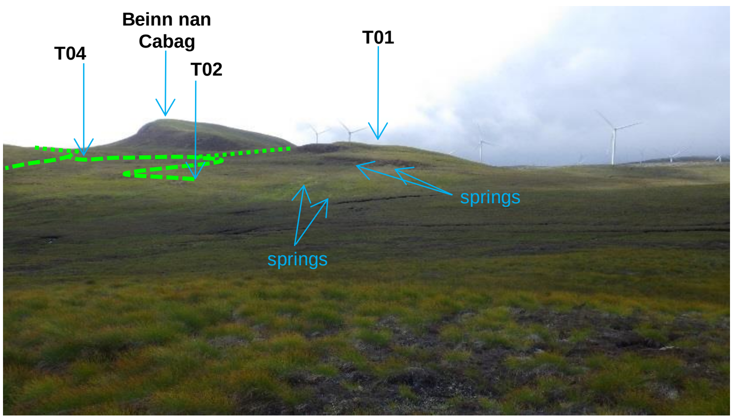
Peat is thin or absent across foreground slope. Vegetation cover is a mat of heather and deer sedge with mineral soil in places.



(D) View across development area looking south-east from NGR NH 3605 6847.

View shows the central block of the development area, including the track crossing of Allt Glac an t-Sìthein.

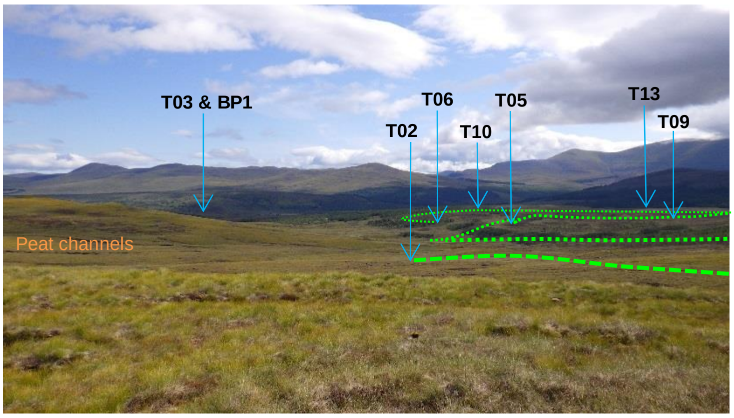
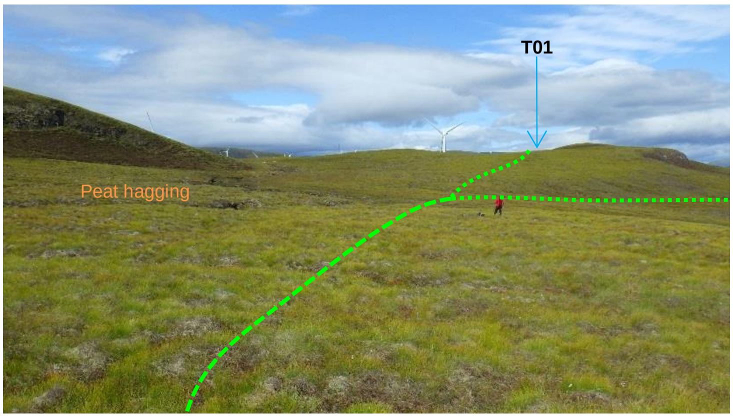
Peat is thin or absent across most of this area. Pockets of deeper peat (>2 m) present near Turbine 9 and south-west (right) of Turbine 8.

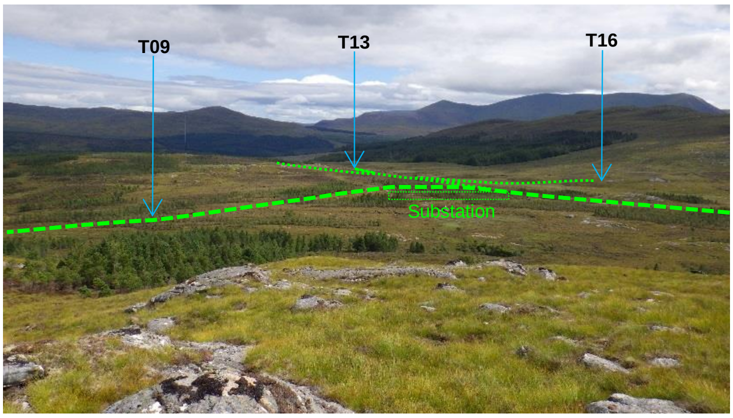


(E) View across development area looking south-west from NGR NH 3605 6847.

View towards Corriemoillie Wind Farm and Beinn nan Cabag, showing western corner of development area.

Peat is variable with some deeper pockets across flatter ground and col to west (right), thin or absent near Turbine 1 and on flanks of Beinn nan Cabag.

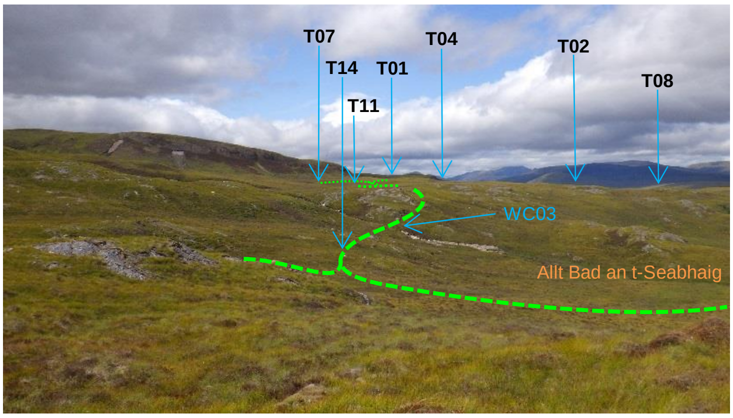
	**(F) View of collapsed peat pipe, NGR NH 3571 6822.** Example of a collapsed peat pipe below col between Sìthean nan Cearc and Turbine 1. Only limited evidence of peat pipes was observed around the project area. View to north-west.
	**(G) View across development area looking north-east from NGR NH 3550 6779.** View shows the northern part of the development area from near Turbine 1. The immediate foreground has no peat. The area around Turbine 3 also has no peat. The flatter area with peat channels has deep peat, and peat is present around Turbine 2 and the near access track.
	**(H) View along south-western margin to north-west from NGR NH 3580 6755.** View from Turbine 4 looking back to Turbine 1, access to Turbine 2, and Corriemoillie Wind Farm. There is some peat development in this area, particularly around the peat hagging to the south (left). The ridge at Turbine 1 has limited or no peat.
	**(I) View of peat hag, NGR NH 3580 6754.** Example of a peat hag south of Turbine 4. Some peat hagging was observed within and around the project area, mainly around Turbines 4 and 7 with limited hagging in other areas. View to south.



(J) View across development area looking north-east from NGR NH 3630 6758.

View shows part of the develop-ment within the woodland area. BP2 is out-of-sight below the rocky foreground.

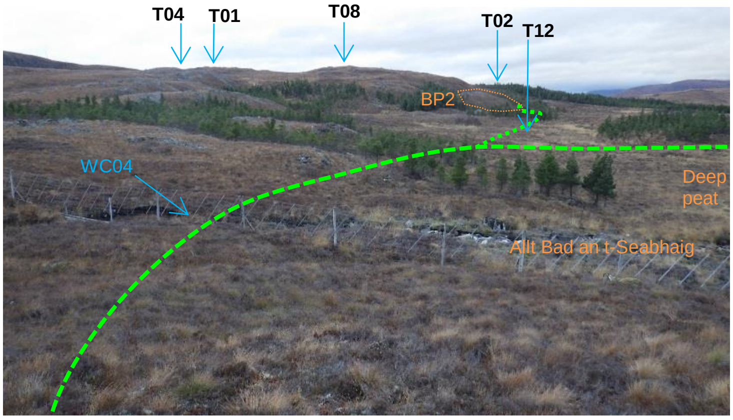
Peat is largely absent from the immediate foreground. Peat cover is variable within the woodland, with some pockets and bowls of peat >2 m, although much of the area has shallow or limited peat.



(K) View across development area looking north-west from NGR NH 3663 6669.

View shows the plateau area below and east of Beinn nan Cabag, plus the upper crossing of Allt Bad an t-Seabhaig.

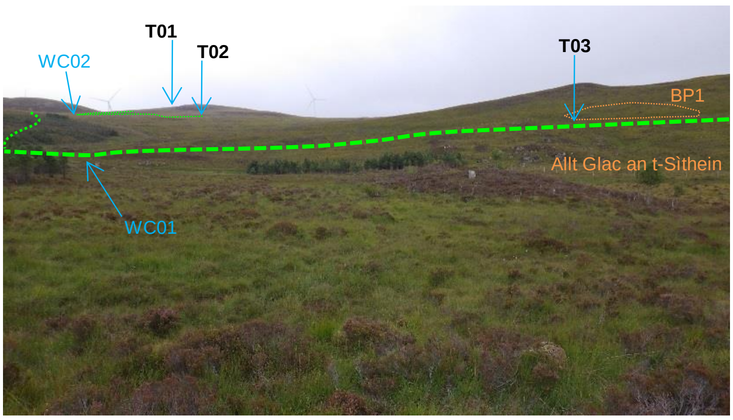
Peat depths across this area are variable, with localised pockets up to 2 m in the foreground. Some areas of peat >2 m are present between infrastructure.



(L) View across development area looking north-west from NGR NH 3681 6724.

View shows the southern part of the woodland area, including BP2 and the lower crossing of Allt Bad an t-Seabhaig.

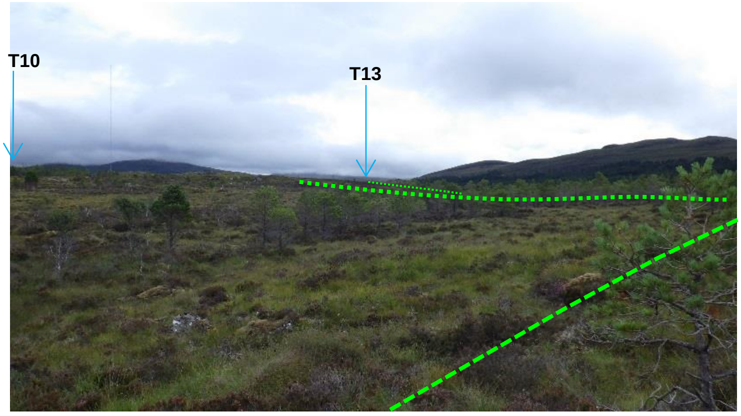
Most of this area has shallow or limited peat cover, with occasional small pockets of deeper peat. The right margin shows part of a bowl of deep peat, skirted by the track route.



(M) View across development area looking west from NGR NH 3677 6836.

View from Turbine 6 shows access into the development area past Turbine 3 and BP1, and the western section.

The plateau between Turbines 2 and 3 has extensive peat. Most of the area has variable peat with some localised pockets of peat >2 m and other areas with limited or no peat.

	**(N) View across development area looking east from NGR NH 3669 6785.** View from Turbine 9 shows a typical section of the woodland area and the north-eastern part of the development. Peat is variable across this area, with pockets of deeper peat in some areas and limited or no peat in others. Bedrock exposure is visible in places.
	**(O) View of drainage ditch within the woodland area, NGR NH 3680 6755.** Example of a drainage ditch near the substation area. Much of the woodland area has drainage ditches present, although drainage remains poor. Note stunted tree growth, associated with waterlogging, and *Sphagnum* moss growth within the ditch.

4 PEAT DEPTH MAPPING

Peat depth survey

4.1 Initial peat depth surveying was undertaken by Quadrat Scotland Ltd in 2014 and 2016, with additional surveying carried out by Avian Ecology in July 2018. A subsequent phase of peat depth surveying was undertaken by RSKW in October and November 2018. The survey results are summarised in Table 9.1.2.

4.2 The peat depth survey was undertaken in two main phases. Phase 1 consisted of a 100 m grid across the survey area in order to develop a picture of the overall pattern of peat development across the original study area. The survey results were used to inform the infrastructure design, in order to minimise incursion into areas of deeper peat.

4.3 Phase 2 focused on areas where infrastructure was proposed. Peat depths were recorded at 50 m intervals along proposed tracks, crosshair probing at turbine base locations and in grids across hardstanding areas, site compounds and buildings, and borrow pit areas.

4.4 Peat probing point locations were recorded using a handheld GPS with typical accuracy of ±5 m and peat depths were measured to an accuracy of ±0.01 m. All measurements were recorded to full depth/point of refusal.

4.5 The peat depth survey indicates that just over half of the survey area has no peat, with 57% of the measured locations having topsoil or peaty soil cover up to 0.5 m deep.

Table 9.1.2: Summary of peat depth probing results

Peat depth range (m)	No. of points	Percentage of points
0.00	20	1.3%
0.01 – 0.50	859	55.6%
0.51 – 1.00	369	23.9%
1.01 – 1.50	146	9.4%
1.51 – 2.00	77	5.0%
2.01 – 2.50	39	2.5%
2.51 – 3.00	15	1.0%
3.01 – 3.50	17	1.1%
3.51 – 4.00	2	0.1%
4.01 +	2	0.1%
Total:	**1,546**	**100.0%**

4.6 The peat depth survey and reconnaissance survey both confirm that areas of peat deeper than 2 m are generally not extensive. The main exception is the col between Sìthean nan Cearc and Beinn nan Cabag, which was subsequently removed from the project area. Most of the areas of peat >2 m are small confined pockets with occasional larger bowl areas, typically associated with natural hollows in the topography and often associated with watercourses or watercourse headwaters. The probing data indicate that the peat depth can vary very substantially over short distances.

Indicative peat depth mapping

4.7 The combined peat depth survey results were used to produce an extrapolated indicative peat depth map for the study area. The extrapolated peat depth map was produced using a Gravity interpolation across the survey area with a 25 m cell size.

4.8 The advantage of using a digital interpolation is that the process is fully objective and there can be no subjective influence. However, the process is not able to allow for known variation in peat development in varying topographical settings. As a result, there may be over-estimation of peat development in areas of steep or well-drained ground, and potential under-estimation of peat development in flatter or poorly drained areas. Owing to the good resolution of the underlying data, the interpolation appears largely to give a representative indication of peat depth across the project area.

4.9 The indicative peat depth map for the project area is provided in Figure 9.1.2.

5 PEAT CONDITION

Developments on peat

Definition of peat

5.1 Scotland's Soils (2018a) classifies peat as:

> *An accumulation of partially decomposed organic material, usually formed in waterlogged conditions. Peat soils have an organic layer more than 50 cm deep from the soil surface which has an organic matter content of more than 60%.*

5.2 Organic soils which are less than 50 cm thick can also support peatland vegetation and as a result are also considered within Scotland's broader peatland system in Scotland's National Peatland Plan (SNH, 2015). These are often described as 'peaty gleys' or 'peaty podzols', reflecting key aspects of the underlying soil. Peaty soils have a higher plant fibre content and are less decomposed than peat.

5.3 Active peatland typically consists of two layers: the surface layer or *acrotelm* and the deeper layer or *catotelm*. The acrotelm contains the living vegetation and consists of living and partially decayed plant material. It typically has a low but variable hydraulic conductivity and allows some through-flow of water within the plant material. The underlying catotelm is denser, with a very low hydraulic conductivity, and is formed from older decayed plant material. The catotelm varies in structure, in some areas retaining a proportion of fibrous material and in other areas being more humified and amorphous. The degree of humification typically increases with depth.

5.4 Underneath the peat-forming layers, the basal substrate can be a mineral soil, a superficial deposit such as glacial material, or bedrock. There may be a transition zone through a mineral-rich peaty layer at the base of the peat, although this is usually no more than 5 cm in thickness.

Importance of peat

5.5 Peatland forms a key part of the Scottish landscape, covering more than 20% of the country's land area, and forming a significant carbon store (Scotland's Soils, 2018b). In addition, peatland is an internationally important habitat.

5.6 Active and healthy peatlands develop continuously, removing carbon dioxide from the atmosphere and storing it within the peat soil. Peatland protection and restoration form key parts of the Scottish Government's Climate Change Plan, which targets restoration of 50,000 hectares (ha) of degraded peatland by 2020 and 250,000 ha by 2030 (Scottish Government, 2018).

5.7 It is therefore important that developments in upland areas, where peat is most likely to be encountered, take recognition of the importance of peatland as a habitat and carbon store. Careful planning of developments, and careful infrastructure design, can remove or minimise the disturbance of peat that would be needed to allow the development to proceed.

Peat condition survey

5.8 As part of the peat depth surveys, information was collected concerning the condition of the peat present within the project area. Scottish Natural Heritage recognises four categories of peatland condition: (1) Near-natural; (2) Modified; (3) Drained; and (4) Actively eroding (SNH, 2018).

5.9 Where present in the project area, the peat is mainly in the form of upland blanket peat. There are two main sub-sections of the project area where peat forms a major part of the soil cover; these sub-sections are described separately below. The other sub-sections of the project area are largely without peat.

South-western area

5.10 The south-western part of the project area is characterised by Modified peatland. This area shows development of peat hagging with some, mainly fairly small, areas of bare peat. *Sphagnum* mosses are present but with lower coverage than would be expected on a Near-natural peatland.

5.11 The area has been modified by grazing, by deer and cattle. The cattle are mainly on the lower slopes outwith the project area and in areas with limited peatland. Deer were observed within the main development area and grazing evidence was apparent in a number of areas. Quadrat Scotland (2015) indicated that both grazing and trampling impacts within this area were low to moderate.

North-eastern area

5.12 The north-eastern part of the project area is characterised by Modified and Drained peatland. This area has been planted with a mix of native woodland species, and a network of drainage ditches has been excavated to encourage tree growth. Although the drainage has not been effective, the peat in much of this area is drier than Near-natural peatland and has areas where heather growth is extensive.

5.13 The woodland area has been partially fenced, but gaps in the fence have allowed deer to gain access, and grazing and trampling evidence were apparent in a number of areas. Quadrat Scotland (2015) indicated that both grazing and trampling impacts within this area were low to moderate.

Peatland restoration

5.14 Parts of both the south-western and north-eastern sub-sections of the project area would potentially be suitable for peatland restoration work. This may include: blocking of natural or artificial drainage channels to encourage re-wetting and regrowth of *Sphagnum* species; reprofiling of gully sides and replacement of vegetation; use of geotextile and/or mulches to prevent erosion and encourage natural regrowth of vegetation; and exclusion of grazers through fencing.

5.15 Peatland restoration proposals for the project are discussed in Technical Appendices 9.4 (Peat Management Plan) and 6.6 (Outline Habitat Management Plan).

6 HAZARD AND RISK ASSESSMENT

6.1 For the purposes of this peat slide risk assessment, the following definition of risk has been adopted:

Risk = Probability of a Peat Landslide x Adverse Consequences

6.2 Probability, or likelihood, can be estimated in a number of ways and should take account of both natural factors and man-made or man-imposed factors that could influence slope stability. Man-made or man-imposed factors can include overgrazing from over-stocking, excavation of drainage ditches or grips, or heather burning for land management purposes. Natural factors can include extreme weather events such as very high intensity rainfall, or prolonged dry periods followed by storms.

6.3 The methods of assessment of likelihood and adverse consequences used here are described below.

Assessing likelihood

6.4 The assessment of likelihood of a peat landslide makes use of the Infinite Slope Model to assess stability of the peat across the slopes in the project area, in line with the Scottish Government guidance (Scottish Government, 2017). The Infinite Slope Model assesses slope stability by calculating the forces resisting failure (shear strength) and the forces inducing failure (shear stress) and taking a ratio of these, known as the Factor of Safety. The Infinite Slope Model equation is as follows:

$$F = \frac{c' + (\gamma - m\gamma_w)\, z \cos^2 \beta \tan \varphi'}{\gamma\, z \sin \beta \cos \beta}$$

where

F =	Factor of Safety, the ratio of forces resisting a slide to forces causing a slide
c' =	effective cohesion of the material; kPa
γ =	specific weight of peat, undrained in situ; kN/m^3
γ_w =	specific weight of water; kN/m^3
m =	vertical height of water table above slide plane, as a fraction of total thickness
z =	peat depth; m
β =	slope of ground surface, assumed to be parallel to the slope of the failure plane; degrees
φ' =	internal angle of friction; degrees

6.5 If $F > 1$, the slope is stable; if $F < 1$ the slope is unstable; if $F = 1$ the forces are exactly balanced. It is possible to state with some confidence, therefore, that if $F > 1.3$ the slope is stable and would have some resistance to change.

6.6 Values assigned to the parameters are provided in Table 9.1.3, along with an explanation for their selection.

Table 9.1.3: Parameters for the Infinite Slope Model

Parameter	Value and Derivation
F	Calculated value
c'	4.89 kPa Published effective cohesion values for peat vary from 4.5 to 60 kPa or more. Published values from recent field tests tend to cluster between 10 and 20 kPa with some higher and lower values recorded. The selected value represents the maximum of a back-calculated minimum c' (see explanation below).
γ	11.77 kN/m^3 Derived from density of peat multiplied by acceleration due to gravity (9.81 m/s^2). Density of peat varies depending on degree of decomposition and water content; published values range from 500 to 1,400 kg/m^3. A typical value from literature studies is 1,200 kg/m^3, giving a specific weight of 11,772 N/m^3.
γw	9.81 kN/m^3 Derived from density of water (1,000 kg/m^3) multiplied by acceleration due to gravity (9.81 m/s^2). This gives 9,810 N/m^3.
m	1 Active peat mire typically has a water level at or just below the surface. The presence of water tends to promote sliding, so choosing a 'fully saturated' value gives a conservative estimate.
z	Where available, measured peat depths have been used. For grid analysis, the maximum interpolated depth within the grid has been taken to provide a conservative estimate.
β	Slope angles have been derived from the DTM for the project area. Grid cell slopes were all derived from the project area DTM.
φ'	5° Quoted internal friction angles for soils vary from 15 to 46°. Peat is usually considered to have a lower φ' value than other soils although this would also vary depending on the degree of decomposition and moisture content of the peat. 5° has been chosen as a realistic but conservative estimate.

6.7 The shear strength, c', has been estimated from project area data. This is undertaken by assuming that the slope is just marginally stable at each point where peat depth has been measured, i.e. the slope has F = 1. The Infinite Slope Model equation can be rearranged to derive a value for c', using the other parameters as described in Table 9.1.3.

6.8 It is important to note that the calculated values of c' for each location represent the *minimum* shear strength needed for the peat to be stable. In fact, the shear strength may be, and in most cases probably is, considerably higher. For example, on very shallow slopes the peat needs only a very low shear strength to remain stable, whereas on steeper slopes a much higher shear strength is required to hold the peat on the slope. For this reason, the higher estimated values of c' are of more relevance as they are more likely to be representative of the actual shear strength of the peat on the project area. For this assessment, the maximum value of the calculated shear strengths has been used in the stability analysis. This gives a value of 4.89 kPa, as stated in Table 9.1.3.

6.9 In order to produce a project area-wide dataset for Factor of Safety, a grid of 50 x 50 m cells was overlain across the project area and a Factor of Safety calculated for each cell.

It is a standard and widely recognised GIS technique to use a regular grid for terrain analyses of this kind. It allows a systematic process across the landscape and minimises the subjectivity of the analysis. The 50 x 50 m cells are referred to as 'grid cells' throughout the analysis.

6.10 The Factor of Safety, F, has been calculated for each peat probing location within the scoping area, and for each grid cell within the project area. A buffer of 250 m around the project area boundary has also been included. The Factors of Safety have been divided into classes, which have been used to map the likelihood of a peat landslide occurring at each point and for each grid cell across the project area. The results are presented in Table 9.1.4.

Table 9.1.4: Summary of Infinite Slope Model results

Likelihood	Factor of Safety	No. of points	% of points	No. of cells	% of cells
Nil	No peat	877	56.8	892	36.0
Negligible	2.5 +	628	40.7	1,407	56.7
Unlikely	1.3 to <2.5	38	2.5	144	5.8
Likely	1.1 to <1.3	0	0.0	21	0.8
Probable	1.0 to <1.1	1	0.1	11	0.4
Almost certain	<1.0	0	0.0	6	0.2
	Totals	**1,544**	**100.0**	**2,481**	**100.0**

6.11 The Likelihood map is provided in Figure 9.1.3.

Assessing adverse consequences

6.12 Potential adverse consequences resulting from a peat landslide cover a wide range, from environmental through to economic and, potentially, harm to life. Scottish Government (2017) gives five examples, as follows:

- Potential for harm to life during construction;
- Potential economic costs associated with lost infrastructure or delays in the construction programme;
- Potential for reputational damage associated with the occurrence of a peat landslide in association with construction activities;
- Potential for permanent, irreparable damage to the peat resource, in terms of both carbon store and habitat, through mobilisation and loss of peat in a landslide;
- Potential for ecological damage to watercourses and waterbodies subject to inundation by peat debris.

6.13 Adverse consequence has been assessed taking account of environmental sensitivity, including potential consequences to water quality from peaty debris and habitat loss by peat removal and by blanketing of sensitive areas with peat debris, and economic significance, including damage to infrastructure and construction delays resulting from a peat landslide, in line with current guidance (Scottish Government, 2017).

6.14 Adverse consequence has been assigned as follows:

- **Very high consequence:** A835, wind turbine foundations, substation, areas of very sensitive habitat/GWDTE, private water supply source;
- **High consequence:** watercourse 50 m buffer, areas of sensitive habitat, turbine hardstandings, substation or construction compounds;
- **Moderate consequence:** areas of moderately sensitive habitat, access tracks;
- **Low consequence:** areas of low sensitivity habitat, borrow pits;
- **Very low consequence:** damaged or degraded habitat.

6.15 Table 9.1.5 below provides a summary of the grid cells in the project area assigned the various consequence ratings. The adverse consequence map is provided in Figure 9.1.4.

Table 9.1.5: Summary of adverse consequence ratings

Adverse consequence	No. of cells	% of cells
Very high consequence	221	8.9
High consequence	454	18.3
Moderate consequence	256	10.3
Low consequence	1,550	62.5
Very low consequence	0	0.0

Risk assessment

6.16 The Likelihood and Adverse Consequence are combined to produce an estimate of risk for each grid cell within the project area. The risk assessment matrix used to combine these two parameters is provided in Table 9.1.6 below.

Table 9.1.6: Risk assessment matrix

		Adverse consequence				
		Extremely high	High	Moderate	Low	Very Low
Peat landslide likelihood	Almost certain	High	High	Moderate	Moderate	Low
	Probable	High	Moderate	Moderate	Low	Negligible
	Likely	Moderate	Moderate	Low	Low	Negligible
	Unlikely	Low	Low	Low	Negligible	Negligible
	Negligible	Low	Negligible	Negligible	Negligible	Negligible

6.17 Table 9.1.7 below provides a summary of the risk ranking for the grid cells across the project area, together with an indication of appropriate mitigation from Scottish Government (2017). The risk ranking map is provided in Figure 9.1.5.

Table 9.1.7: Summary of risk ranking and appropriate mitigation

Risk ranking	No. of grid cells	% of grid cells	Appropriate mitigation
High	0	0.0	Avoid project development at these locations
Moderate	19	0.7	Project should not proceed unless risk can be avoided or mitigated at these locations, without significant environmental impact, in order to reduce risk ranking to low or negligible
Low	215	8.7	Project may proceed pending further investigation to refine assessment, and mitigate hazard through relocation or re-design at these locations
Negligible	1,355	54.6	Project should proceed with monitoring and mitigation of peat landslide hazards at these locations as appropriate
No peat	892	36.0	No peat landslide hazard

6.18 Most of the project area has been assessed as having a negligible risk of peat landslide, or of having no peat (90.6%). Nineteen grid cells have been assessed as having a moderate risk of peat landslide and none with a high risk.

6.19 Of the 19 grid cells assessed as having moderate risk, only two are located within the project area. These cells and their immediate surroundings have been the subject of further investigation in order to refine the assessment in these areas. This is detailed in Section 7.

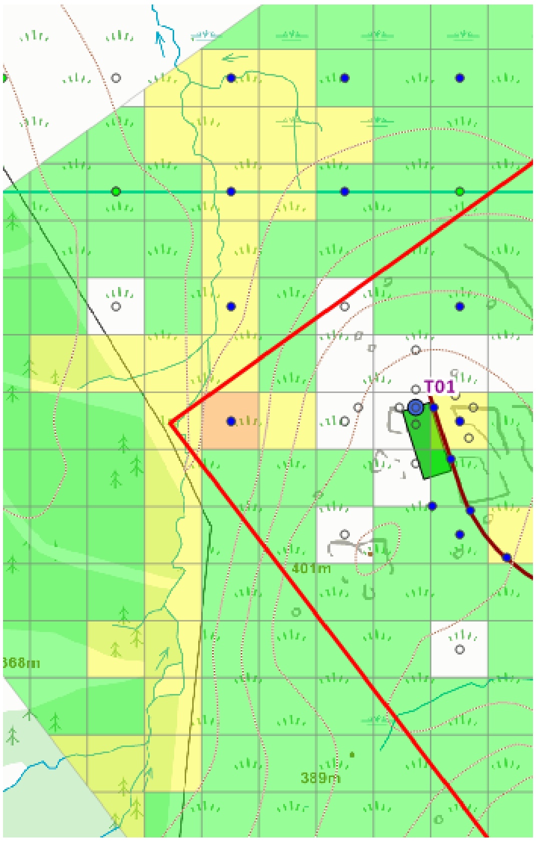
6.20 The remaining 17 cells have not been considered further as there would be no development in or near these cells.

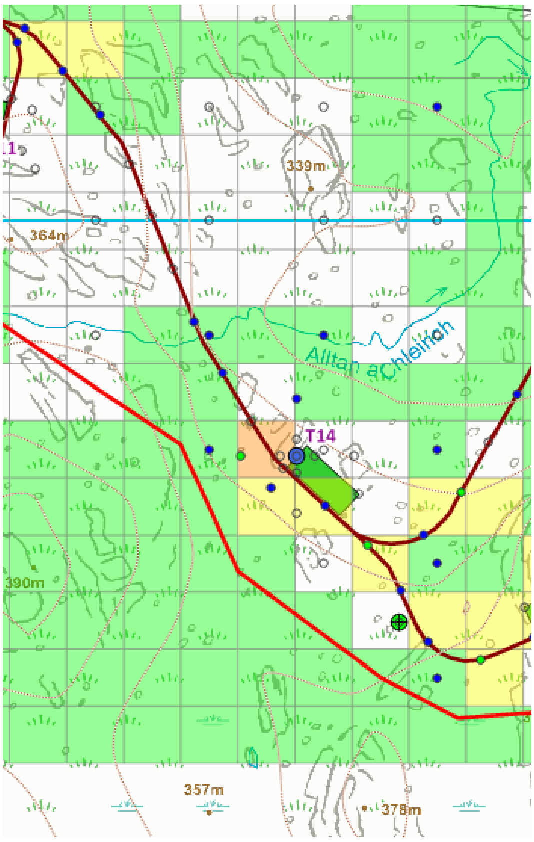
7 DETAILED ASSESSMENT AND MITIGATION

7.1 Two grid cells within the project area have been identified as having a moderate risk of peat landslide. Both cells have been considered in greater detail, including a detailed inspection of the highlighted cells, the cells immediately around them, the measured peat depths and slope angles present, drainage features and the nature of the proposed nearby infrastructure. Mitigation measures are recommended to reduce or control the risk for each area. The areas identified for detailed assessment are indicated on Figure 9.1.5.

7.2 Following detailed consideration, the risk ranking has been re-appraised in the light of the presented information and proposed mitigation. Each description is accompanied by a map of the cell and its immediate surroundings. The grid cells in each map are 50 x 50 m, to give an indication of scale. Green cells have negligible risk; yellow cells have low risk; orange cells have moderate risk. Blank cells have no peat as defined in the PLHRA Guidelines (Scottish Government, 2017).

7.3 The points on the maps show the calculated Likelihood rating for all locations with directly measured peat depth, where blue is negligible; green is unlikely; yellow is likely; orange is probable; and red is almost certain.

 	**Area 1:** One cell in the westernmost corner has been assigned Moderate Risk. This relates to the sensitivity of the receptor, the Allt Giubhais Beag, and its associated High consequence rating. The Allt Giubhais Beag provides a water supply for the Aultguish Inn, with the intake located downstream of this cell. Calculated likelihood for the cell is Negligible, reflecting the combination of peat depth and slope present within the cell. The only infrastructure upslope of the cell is Turbine 1, which is located in an area with no peat. There is therefore no risk of a peat landslide from Turbine 1. There is no activity planned to take place within the highlighted cell. **Mitigation** No activity would take place within the highlighted cell. Sediment management protection would be installed between the works at Turbine 1 and the watercourse in order to protect the watercourse from silty runoff arising from the ground works at Turbine 1. Work in the area would be under supervision of the Environmental Clerk of Works. **Revised risk ranking:** Negligible



Area 2:

Once cell, coinciding with part of Turbine 14's foundation and part of the access track to Turbine 11, has been assigned Moderate Risk. This relates to the sensitivity of Turbine 14, as an important piece of infrastructure, which has a High consequence rating.

The cell is located partly on a small pocket of peat, with one peat measurement at the western side of 2.0 m. The eastern side, around Turbine 14, has no peat. The deep peat record combined with the slope angles within the cell have resulted in a higher Likelihood rating for the cell than for any of the individual peat depth measurements within its footprint. Close inspection identifies that the deep peat measurement and the steeper slopes are not coincident and therefore that the risk associated with Turbine 14 and the track section is lower than indicated.

Mitigation

The location of Turbine 14 and the track route have been carefully designed to avoid the area of deep peat identified here and incursion into the deep peat pocket would be kept to a practical minimum.

Good construction methods would be used at all times, following current guidance. Appropriate cross-track drainage would be installed to provide hydraulic continuity and to help maintain slope stability.

Revised risk ranking:

Negligible

Mitigation

7.4 The following mitigation measures would be implemented to ensure that slope stability is maintained across the project area and to minimise the risk of inducing a peat slide.

7.5 Construction work would make use of current best practice guidance relating to developments in peatland areas. A risk management system, such as a geotechnical risk register, would be developed as part of the post-consent detailed design works. This would be maintained through all subsequent stages of the project and updated as necessary whenever new information becomes available. During construction, and decommissioning as required, members of project staff would undertake advance inspections and carry out regular monitoring for signs of peat landslide indicators. A geotechnical specialist would be on call to provide advice, if required by project area conditions.

7.6 Micrositing would be used to avoid possible problem areas. This would be assisted by additional verification of peat depths, to full depth, in any highlighted areas where construction work is required. Track drainage would be installed in accordance with published good practice documentation and would be minimised in terms of length and depth in order to minimise concentration of flows.

7.7 Construction activities would be restricted during periods of wet weather, particularly for any work occurring within 20 m of a watercourse or within areas of identified deeper peat. Careful track design would ensure that the volume and storage timescale for excavated materials would be minimised as far as practicable during construction works.

7.8 Vegetation cover would be re-established as quickly as possible on track and infrastructure verges and cut slopes, by re-laying of excavated peat acrotelm, to improve slope stability and provide erosion protection. Additional methods, including hydroseeding and/or use of a biodegradable geotextile, would be considered if necessary in specific areas.

7.9 Construction staff would be made aware of peat slide indicators and emergency procedures. Emergency procedures would include measures to be taken in the event that an incipient peat slide is detected.

Infrastructure design

7.10 Careful and informed infrastructure design forms a key measure for prevention of induced instability in peat. The collated peat depth information has been used to inform the proposed infrastructure layout throughout the design process. Incursion into areas of deeper peat would be kept to a practical minimum by careful design and micrositing, in order to minimise disruption to peatland ecosystems and hydrology, and to avoid the risk of induced peat instability.

7.11 Access tracks are anticipated to be constructed using established cut-and-fill construction methods. Any peat present along the route would be excavated and stored for use in reinstatement of trackside verges and other elements of project infrastructure where appropriate.

7.12 Trackside ditches would be constructed as required. For tracks parallel or sub-parallel to contours, best practice recommendations are for a ditch along the uphill side only, with cross-drains installed at regular intervals below the track to minimise flow concentration. Cross-drains would discharge onto vegetated ground where possible, to encourage spread of surface flow rather than focused flow and the consequent development of new drainage channels. Tracks crossing contours may require ditches or swales on both sides. In all cases, lengths and depths of trackside drainage would be minimised. There would be a requirement for some trackside drainage to minimise track surface erosion and damage.

8 CONCLUSIONS

8.1 A detailed assessment of peat slide risk has been carried out for the proposed Kirkan Wind Farm. All proposed new and upgraded infrastructure has been covered by the assessment.

8.2 The assessment found that the majority of the project area has a negligible or low risk of peat landslide. Two areas within the project area identified as having a moderate risk of peat instability were appraised in greater detail, taking into account location-specific details. For both areas, mitigation measures have been recommended to control the peat landslide hazard. For both areas, the peat landslide hazard can be controlled by use of good construction practice and micrositing.

8.3 Good construction methods and appropriate micrositing would also be effective at controlling residual peat landslide risk for lower risk locations at the project area. Providing that the recommended mitigation measures are put in place and adhered to, the risk of peat landslide as a result of the Kirkan Wind Farm development is not significant.

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10 ANNEX: AUTHOR EXPERIENCE

The author of this report, Catherine Isherwood, is a Chartered Geologist with an MA and PhD in Geological Sciences from the University of Cambridge and an MSc in Hydrogeology from Newcastle University. She has over 12 years' experience in environmental impact assessment and the assessment of peat and slope stability.

The report has been reviewed and authorised by Andrew Gunning, a Chartered Geologist and Chartered Engineer.

The assessment method was developed with input from a Chartered Engineer and a Chartered Environmentalist with a combined experience of more than 35 years.